Development of Tools for Remote Detection and Prediction of Low-Strength Muds in Energetic Coastal Environments

Timothy G. Milligan
Fisheries and Oceans Canada
Bedford Institute of Oceanography
1 Challenger Drive
Dartmouth, Nova Scotia, CANADA B2Y 4A2
phone: (902) 426-3273 fax: (902) 426-6695 email: timothy.milligan@dfo-mpo.gc.ca

Paul S. Hill
Department of Oceanography
Dalhousie University
Halifax, Nova Scotia, CANADA B3H 4J1
phone: (902) 494-2266 fax: (902) 494-3877 email: paul.hill@dal.ca
http://www.phys.ocean.dal.ca/~phill

Grant Numbers: N00014-08-1-1002, N00014-08-1-1001

LONG-TERM GOALS

The goal of our Tidal Flats research is to expand our understanding of the erosional and depositional processes that lead to exchange of mud between tidal channels and tidal flats and its impact on sediment strength.

OBJECTIVES

Our research on Tidal Flats DRI has two primary objectives:

1. Improve understanding of how turbulence and sediment concentration affect the size-dependent depositional flux of sediment to the seabed on tidal flats.

2. Improve understanding of how sediment texture and sorting in the seabed affect the size-dependent erosional flux from the seabed on tidal flats.

APPROACH

We have focused our studies on two compositionally different sites at the Southern end of Willapa Bay, WA, that were identified during a regional grain size survey conducted in September 2008 (Figure 1). The first is a muddy site located near the secondary channels and flats west of the Bear River channel near Round Island. The second, sandier, more exposed site is located at a lower tidal level approximately 2.5km to the northwest of the first site. Cores for erodibility studies were collected from the channels and flats from both sites. Suspended sediment measurements have been

Report Documentation Page			*Form Approved* *OMB No. 0704-0188*

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE **2009**	2. REPORT TYPE	3. DATES COVERED **00-00-2009 to 00-00-2009**
4. TITLE AND SUBTITLE **Development of Tools for Remote Detection and Prediction of Low-Strength Muds in Energetic Coastal Environments**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Bedford Institute of Oceanography,Fisheries and Oceans Canada,1 Challenger Drive,Dartmouth, Nova Scotia, CANADA B2Y 4A2,**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**		
13. SUPPLEMENTARY NOTES		
14. ABSTRACT		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**7**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

concentrated at the muddy site in order to collect spring-neap time series and to help understand changes in flux that may result in low strength muds.

.

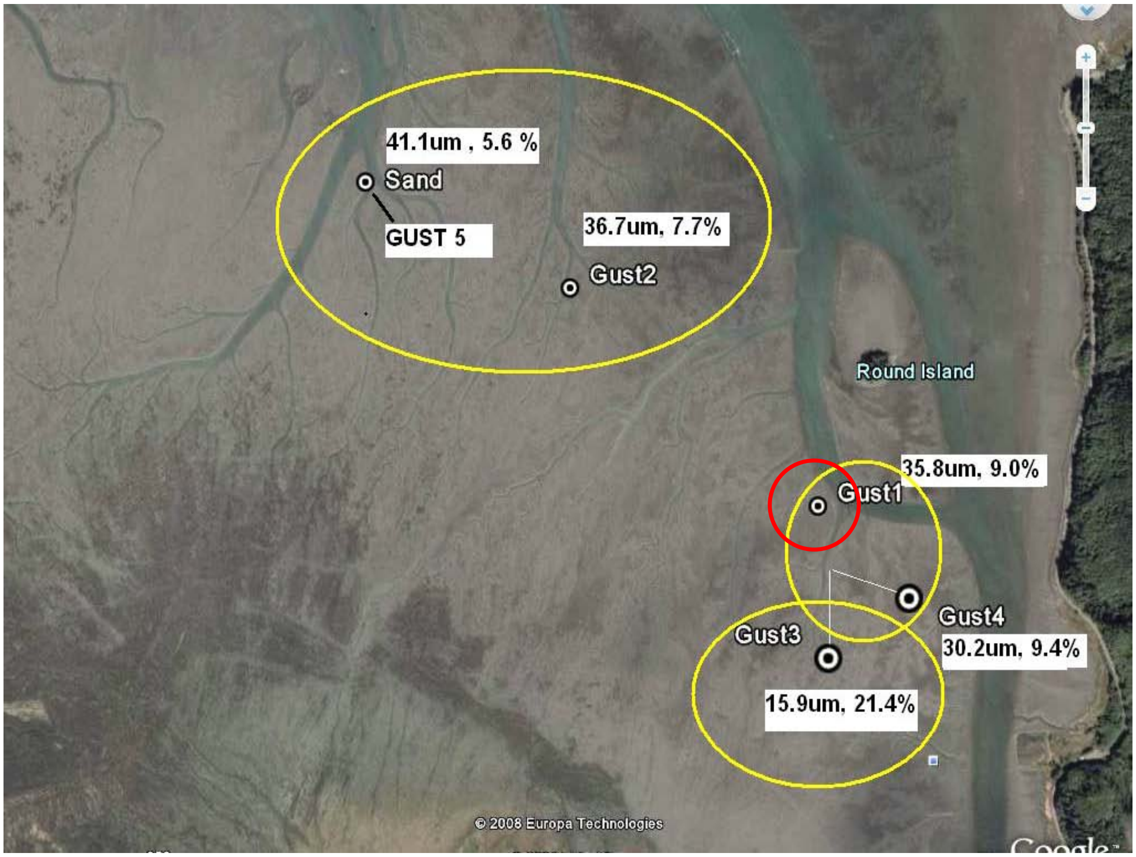

Figure 1: Location map for Willapa Bay Tidal Flats coring and suspended sediment observations. Yellow denotes areas where cores were collected for erodibility studies in September 2008 and March and July 2009. Red shows area where suspended sediment measurements and erodibility studies were carried out in March and July 2009. Labels indicate geometric mean diameter of disaggregated inorganic bottom sediments and volume percentage less than 4 μm in diameter. The site SSW of Round Island is finer grained than the site NW of Round Island. Image is ~4km wide.

WORK COMPLETED

To examine seasonal variations in sediment dynamics, experiments were carried out on the Willapa tidal flat in September 2008 and March and July 2009. Sediment cores were collected to determine erodibility at stations located on both the tidal flat and in channels. Cores with undisturbed sediment-water interfaces were obtained using a specially designed hand held corer from small boats and kayaks. A Gust erosion chamber was used to erode sediment at known shear stresses and this material was collected for disaggregated inorganic grain size (DIGS) analysis. In addition a regional survey of surficial sediment grain size was conducted in September and July. In September and March a LISST 100x, digital floc camera (DFC), and a digital video camera (DVC) attached to a settling column were deployed to examine in-situ particle size and settling velocity (Figure 2). Measurements were made at both the sand and mud flat sites. In July, a second LISST and DFC were added to the survey to allow simultaneous measurements of in-situ particle size in both the channel and flat at the mud site and to make simultaneous measurements on the flat at the sand and mud sites.

Figure 2. Instruments on the Willapa Bay tidal flat. From left to right, Digital Settling Velocity Camera (DVC), LISST 100x, Digital Floc Camera (DFC), and 2 Nortek Aquadopps™ (on loan from Washington State University in Vancouver).

RESULTS

Several basic results are emerging from our work to date.

- Suspended sediment concentration, floc size, and settling velocity are maximal when currents are strongest. This observation indicates that gross downward flux due to sinking is maximal at peak currents (Figure 3).
- Suspended sediment concentration, floc size, and settling velocity are larger on flood tides than on ebb tides. This observation indicates that there is asymmetry in vertical and horizontal flux at the height of our sensors (0.5 mab), with net flux of fine sediment onto the tidal flats (Figure 3).
- Size sorting during erosion depends on bed sediment texture. When the percentage of sediment smaller than 4 μm is less than 5-10%, sediments behave non-cohesively. When this fraction is higher, all sediment smaller than ~16 μm is resuspended equally (Figure 4; Law et al., 2008). This observation indicates that sandy sites will remain sandy, and muddy sites will accumulate more mud.

- The DIGS for surficial sediment samples collected in March has a larger proportion of floc settled material than samples from September. July samples still require analysis to determine trend on a longer temporal scale.

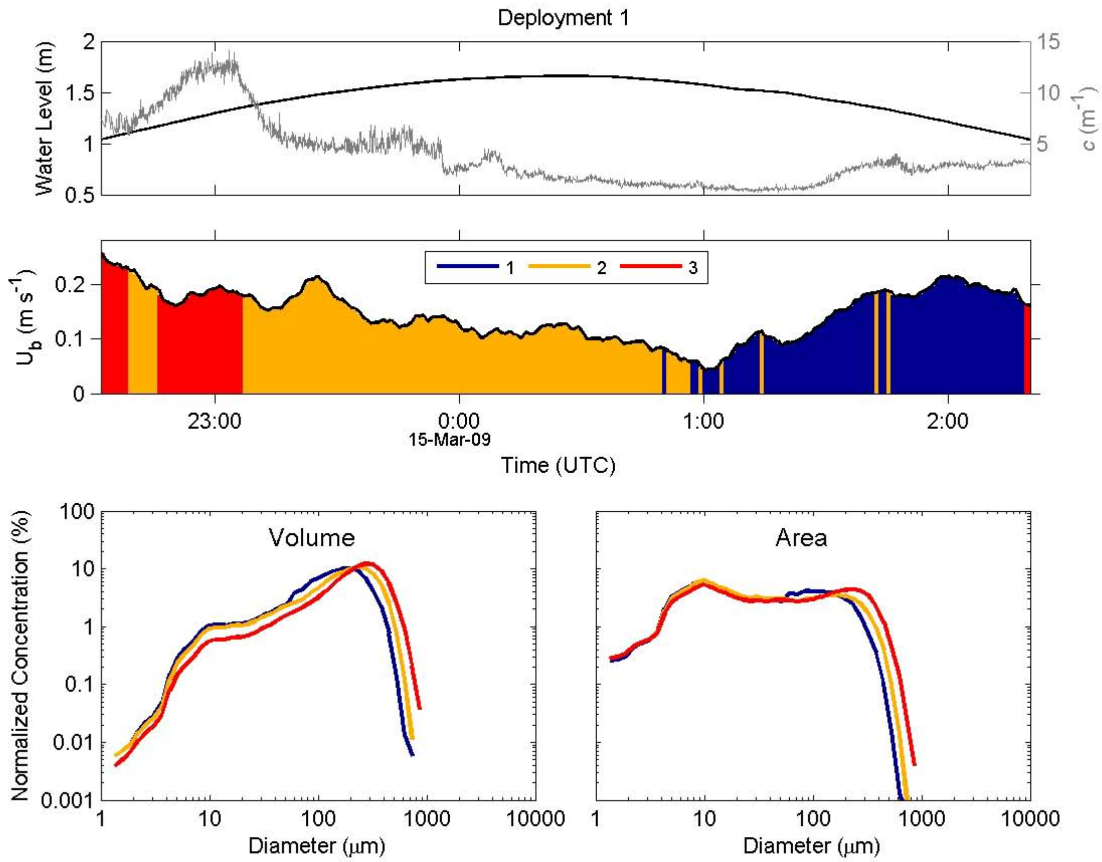

Figure 3. Time series of water level, beam attenuation and particle groups on a muddy tidal flat in Willapa Bay. In the top panel, as water level (black line) increases, beam attenuation(gray line) increases. At high water beam attenuation decreases indicating that sediment is settling from suspension. As water level falls on the ebb, attenuation increases again, but not to the magnitude that it had on the flood tide. In the second panel, a time series of bottom current speed is plotted using a fill color that corresponds to the dominant particle size entropy group shown in the bottom panels. Entropy analysis groups particle size spectra in a way that maximizes both similarity among size distributions within a group and differences among size distributions between groups (Mikkelsen et al., 2007). Particle size distributions indicate that flocs are larger on the flood than on the ebb. The asymmetry between beam attenuation and particle size on the flood versus the ebb can not be explained by shoreward pumping of fine sediment. It may indicate that there is flow stratification on the ebb tide that prevents flocs from diffusing to the height of the particle sensors 0.5 mab.

The observations fit into a conventional model of sedimentation on mudflats. According to the conventional model, sands on tidal flats are found below the mid-water level, on parts of the seabed that experience maximum tidal flows. The sand site and the channels at the mud site are in this category (Figure 1). Muds are found higher on the flats. Because of the longer period required for muds to sink from suspension, they are carried landward on flooding tides, and they deposit at high slack water. Because of cohesion, freshly deposited muds are not re-eroded on the ebb tide. This model generally fits our observations of particle size and size sorting during erosion. The hypothesis that freshly deposited mud on the upper flats is not re-eroded on ebb tides, however, is difficult to reconcile with other observations.

In general, sediment on the muddy flats is difficult to erode, suggesting that there is little freshly deposited sediment at the surface. In contrast, sediment in the channels tends to be more mobile. This observation could be due to the cohesive behavior of sediment on the muddy flats versus the non-cohesive behavior at sandier sites. This hypothesis requires rapid and significant cohesion of freshly deposited muds, and it has difficulty explaining the presence of easily eroded muds in channels and at sandy sites. According to the conventional model, the easily eroded muds should be exported to muddy flats and remain there, which in the absence of a significant sediment source would leave the sandy flats and channels depleted of fine mobile sediment. An alternative hypothesis, supported by Chuck Nittrouer's observations from a jack-up barge, is that freshly deposited mud on the upper flats is re-eroded on ebb tides and is returned to the lower flats and channels. This suspended material is not measured by our particle sensors 0.5 mab because of water column stratification, which limits the upward turbulent diffusion of flocs and/or generates differential floc breakage on flood versus ebb tides because of suppression of turbulence (e.g., Scully and Friedrichs, 2007).

Resolving the fate of fine sediment advected onto the upper flats is critical to the prediction of trafficability. If freshly deposited fine sediment remains on the upper flats, then these areas pose the greatest problem for trafficability. If, on the other hand, fine sediments return to the channels on each ebb tide, then these areas are more prone to accumulation of low-trafficability muds. We hypothesize the latter scenario, and future work will test this hypothesis by conducting simultaneous measurements of sediment flux and erodibility on the flats and in an adjoining channel.

IMPACT/APPLICATION

Physical properties of the seabed depend fundamentally on particle size. This dependence endows energetic coastal tidal flats with extraordinary variability in seabed properties, because these are the only environments on Earth where mud, sand, and gravel are all actively eroded, transported, and deposited. Over the course of a single tide, a spring-neap tidal cycle, a season, or a year, seabed grain size at a single location can change dramatically on an energetic flat (e.g., Choi et al., 2004).

Variability in seabed properties represents a major concern for safe and efficient travel across tidal flats. Especially problematic are "oozing mudflats" (cf. Wells, 1983, Frey et al., 1989) with high porosity and low strength. People and equipment can sink deeply into such muds, making travel difficult and potentially dangerous. The link between seabed properties and "trafficability" motivates efforts to understand the formation of low-strength muds so that models that can predict the locations of such deposits can be developed.

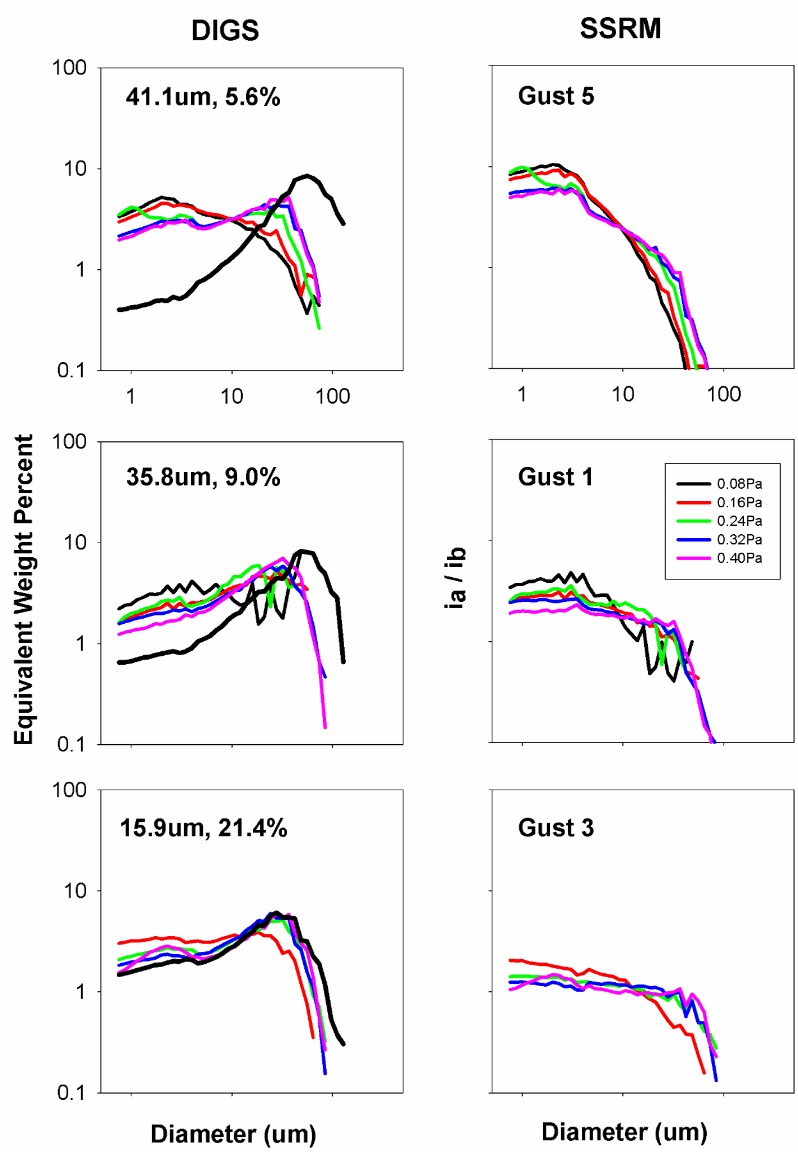

Figure 2. Results from erosional sorting studies carried out on three cores from Willapa Bay in September 2008 collected at three sites: top = sand, middle = mud flat, bottom = mud channel. Left panels show DIGS of bottom sediment (black) and material eroded at increasing stress (colored) with corresponding geometric mean diameter percentage of sediment < 4 μm. Right panels show, size-specific relative mobilities (SSRM) for the eroded cores. The SSRMs divide the relative concentration in a size class in suspension by its relative concentration in the bed. Values greater than one indicate preferential erosion of that size class, while a value of one indicates that the particle size has the same relative concentration in suspension as it does in the bed, i.e. there has been no size sorting. The pattern in the sand core is consistent with non-cohesive behavior, which generally occurs when the fine fraction is less than 5-10% (Law et al., 2008). The channel core shows SSRMs near to unity over a range of size classes, indicating cohesive behavior and minimal size sorting. This behavior is consistent with its large fine fraction. The GUST 1 core shows intermediate sorting behavior, consistent with its fine fraction of 9%.

RELATED WORK

This work is being carried out in close collaboration with other ONR sponsored researchers. Cores collected were also measured for erosion rates and cumulative mass eroded (Pat Wiberg, UVA), porosity and organic content (Rob Wheatcroft, OSU), and fracture strength (Bernie Boudreau and Bruce Johnson, Dalhousie). Chuck Nittrouer carried out a regional coring program to determine sediment source and accumulation rates on the Willapa flats. Results from the in-situ measurement of particle size, transmission (C_p), and settling velocity are being applied to the ONR funded Ocean Optics OASIS project.

REFERENCES

Choi, K. S., R. W. Dalrymple, S. S. Chun, and S.-P. Kim. 2004. Sedimentology of modern, inclined heterolithic stratification (IHS) in the macrotidal Han River delta, Korea. Journal of Sedimentary Research, 74: 677-689.

Frey, R. W., J. D. Howard, S.-J. Han, and B.-K. Park. 1989. Sediments and sedimentary sequences on a modern macrotidal flat, Inchon, Korea. Journal of Sedimentary Petrology, 59: 28-44.

Law, B. A., P. S. Hill, T. G. Milligan, K. J. Curran, P. L. Wiberg, and R. A. Wheatcroft, 2008. Size sorting of fine sediments during erosion: Results from the western Gulf of Lions, Continental Shelf Research 28: 1935-1946.

Mikkelsen, O.A., K.J. Curran, P.S. Hill, and T.G. Milligan, 2007. Entropy analysis of in situ particle size. Estuarine, Coastal and Shelf Science, 72(4): 615-625.

Scully, M. E. and C. T. Friedrichs, 2007. Sediment pumping by tidal asymmetry in a partially mixed estuary. Journal of Geophysical Research, 112(C7).

Wells, J. T., O. K. Huh, and Y. A. Park. 1983. Dispersal of silts and clays by winter monsoon surges in the southeastern Huanghai Sea. In: Proceedings of the International Symposium on Sedimentation on the Continental Shelf, Hangshou, China: Beijing, China Ocean Press, v. 1, pp. 462-472.